Modeling Stratospheric Ozone Loss and Recovery

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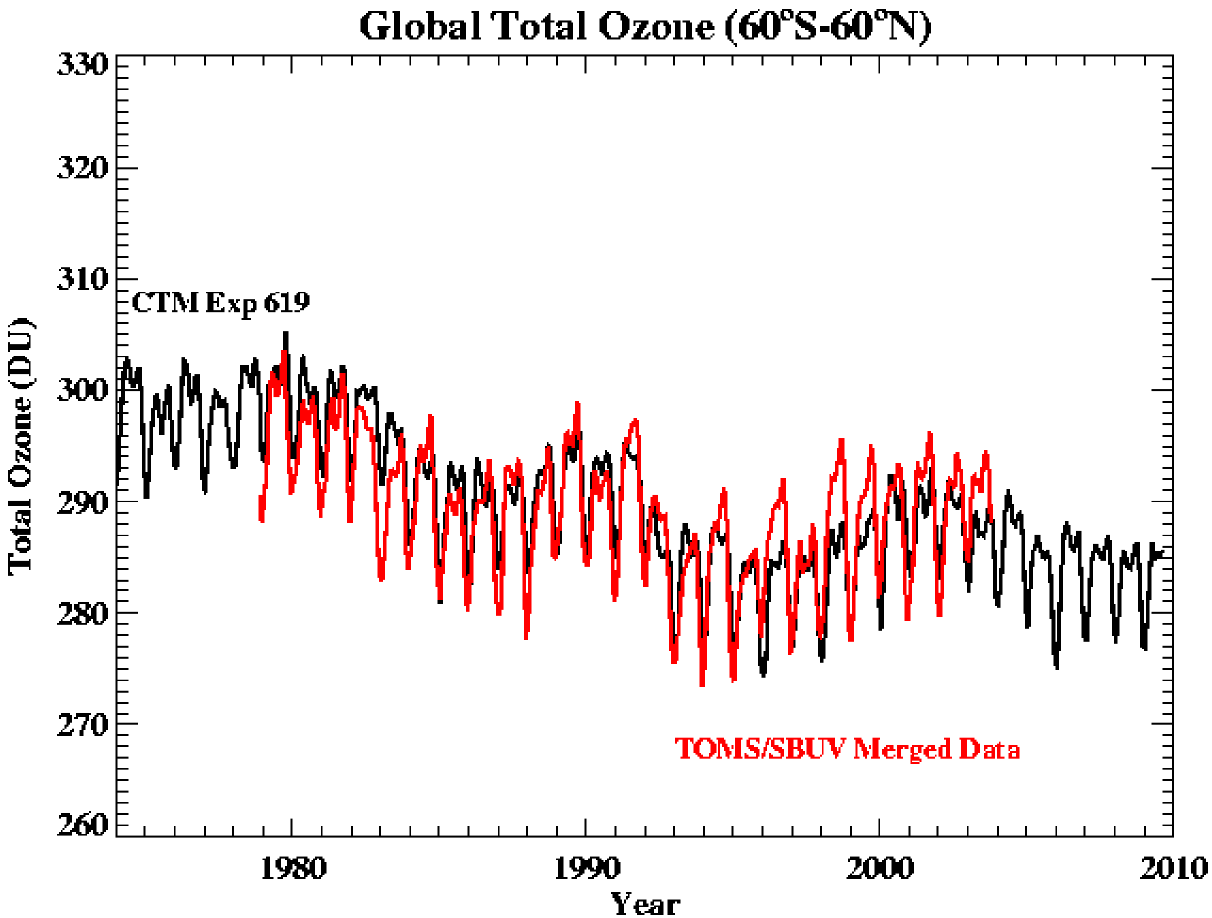
Understanding the Past is the Key to Predicting the Future

- **We have used our CTM to do 50-year hindcast/forecast for stratospheric composition (1973-2022) including chlorine/bromine forcing, solar cycle uv, and volcanic aerosols**
- **The simulation used GCM dynamics with model-generated interannual variability**
- **We have rerun 1979-1999 without volcanic aerosols**
- **We have restarted in 1973 and set off the Pinatubo volcano in 1975, a time of lower chlorine concentration**

“Global” Total Ozone from CTM Simulation Compared to TOMS/SBUV Data



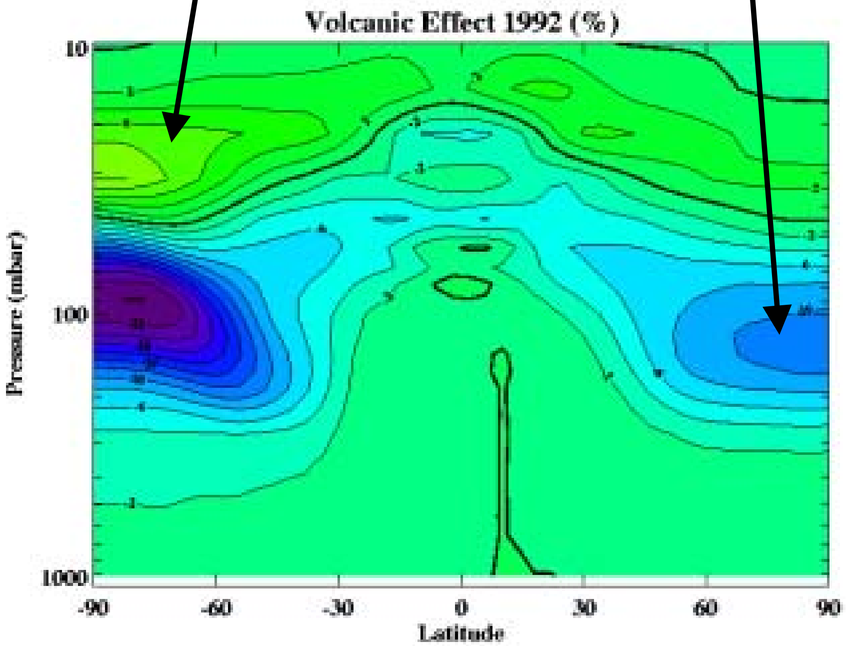
Little bias, apparent solar cycle, downward trend, and probably a volcanic effect due to aerosols: but it is difficult to evaluate volcanic effect. We can rerun the model without aerosols and subtract to get volcanic term.

What is the Pinatubo Effect on Ozone in the Model?

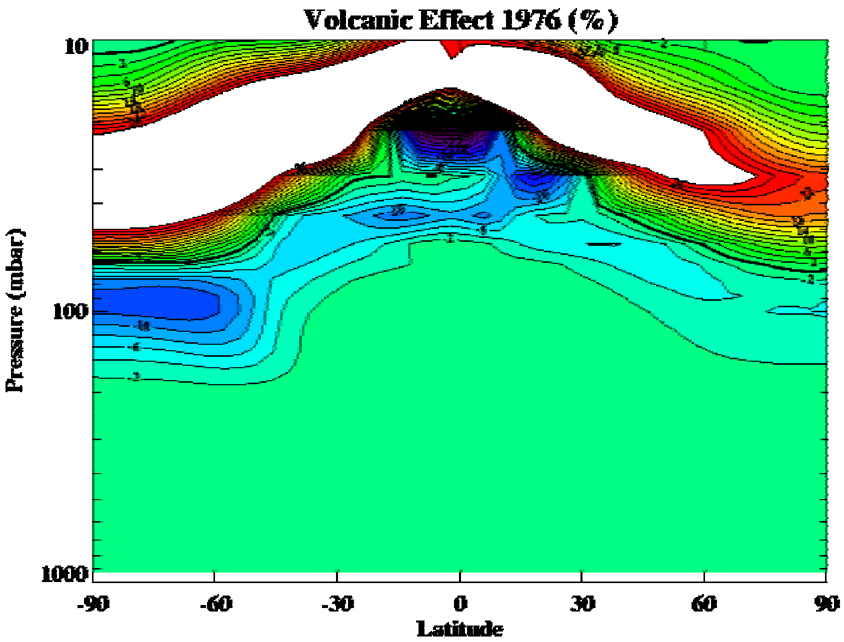
Aerosols reduce NOx --> less NOx loss, more ClOx loss

NOx wins **ClOx wins**

1992



1976

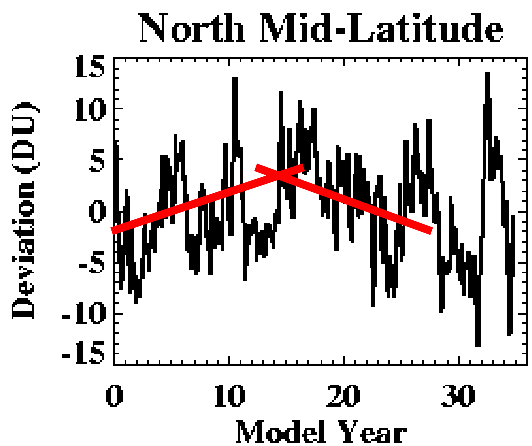


Dynamical Component of Trend

- **“Accidental” dynamical component**
  - **Statistical effect due to shortness of record**

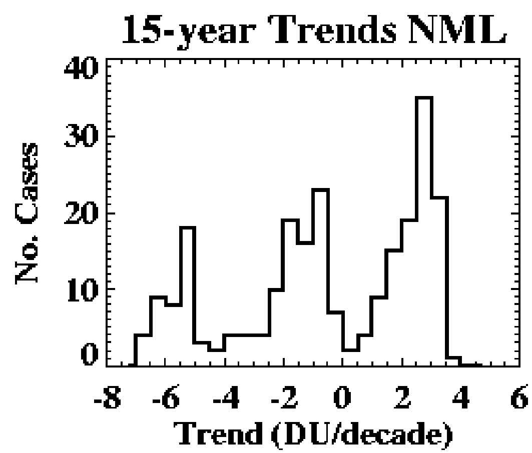
- **“Forced” dynamical component**
  - **Driven by ozone change or climate change**

Determining the probability of randomly-generated trends from model variability (the “accidental” trend)



Residual on-line parameterized ozone time series after removal of seasonal variation:

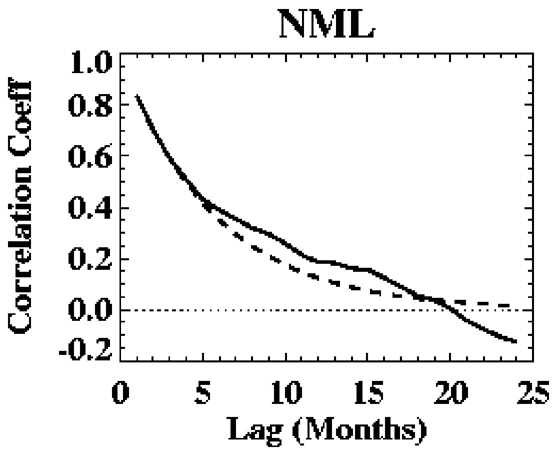
We can fit straight line trends through various sections of the data (fit a line, then Move over one month and repeat).



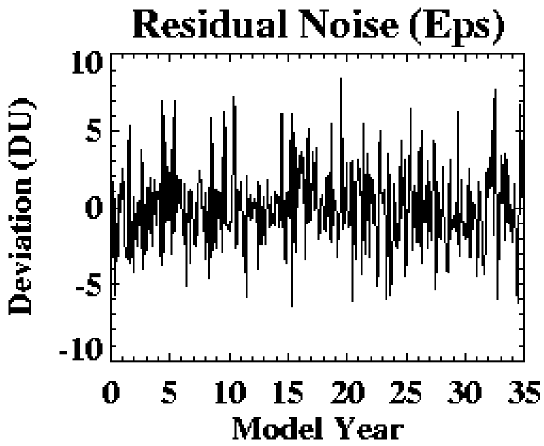
And then we can plot the probability distribution of the slopes.

The result in this case is tri-modal in this Case because we have only 35 years and are Fiiting 15-year slopes-they are mostly redundant

Statistical Characterization of theTime Series



Auto correlation coefficient versus time lag in months (dashed line is lag 1 coefficient raised to the nth power where n is the lag)

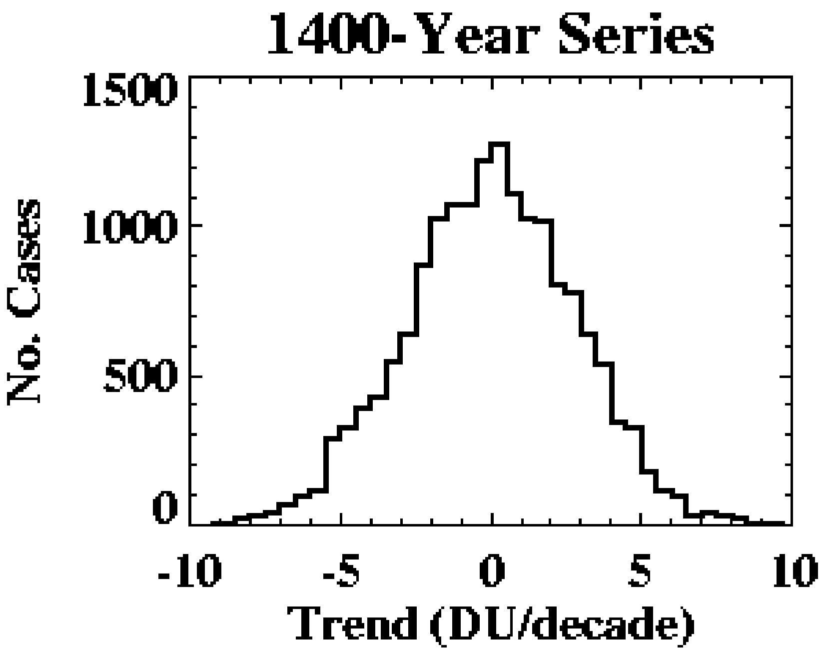


Residual white noise after removal of auto-regressive component. Series can be Represented by AR-1 model with

$$x(t) = \phi\, x(t-1) + \varepsilon(t)$$

where ϕ =0.82 and ε is gaussian noise with standard deviation of 3.5 DU (check no.)

Trend PDF from Artificially-Created Time Series



We can use the ϕ and ε from the AR-1 model to construct artificial time series of arbitrary length. This time series can then be fitted with trends over 15-year periods to produce a PDF that is gaussian. The standard deviation of this distribution gives the uncertainty introduced into trends by statistical variability of the model.

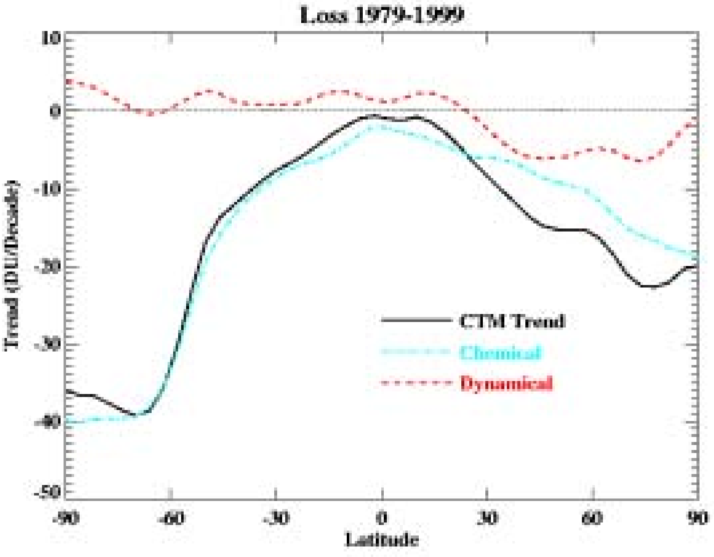
2σ Uncertainty (15-year Trends)

Region	DU/decade	%/decade
NML	5.6	1.8
Equator	4.4	1.7
SML	6.4	2.0
Global	1.0	0.35

Trends Deduced from CTM Simulation

- **All in DU/decade**
- **Dynamical trend from on-line parameterized ozone tracer**
- **Chemical trend from difference between CTM ozone and ozone tracer**

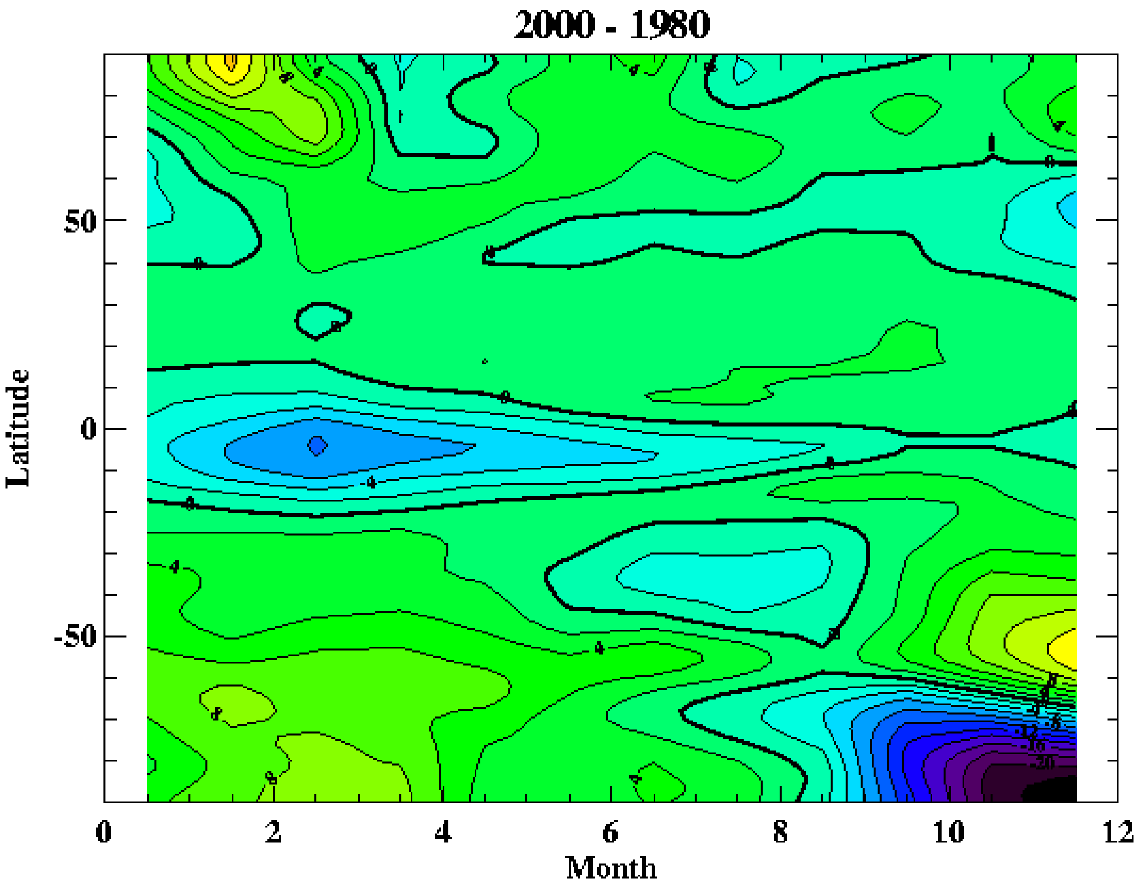
Region	Dates	Dynamical Trend	Chemical Trend	Model Trend
Global	1979-1999	+0.2	-7.4	-7.2
50°N	1979-1999	-5.9	-8.6	-14.5
Global	1995-2022	-2.2	+3.9	+1.7
50°N	1995-2022	-0.4	+3.1	+2.7



Forced Dynamical Component of Trend

- **We have carried out two 20-year simulations of the GCM using different ozone climatologies in the radiation code**
  - ***Pre-ozone hole: 1978-1980 mean from CTM***
  - ***Ozone hole: 1998-2000 mean from CTM***
- **Zonal monthly mean climatologies were used in each case**

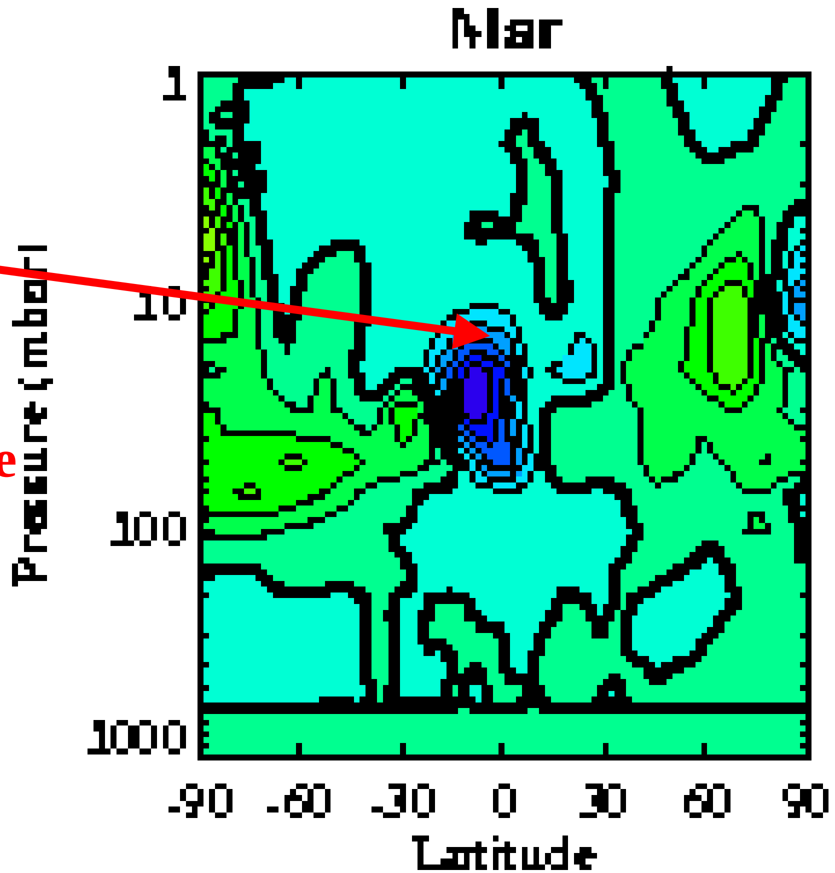
Mean Difference Between 20-Year Simulations with Pre and Post Ozone Hole Ozone in Radiation Code: Total On-Line Parameterized Ozone



P and L for ozone are exactly the same in both runs: the only difference is the transport

Mean Difference Between 20-Year Simulations with Pre and Post Ozone Hole Ozone in Radiation Code: March

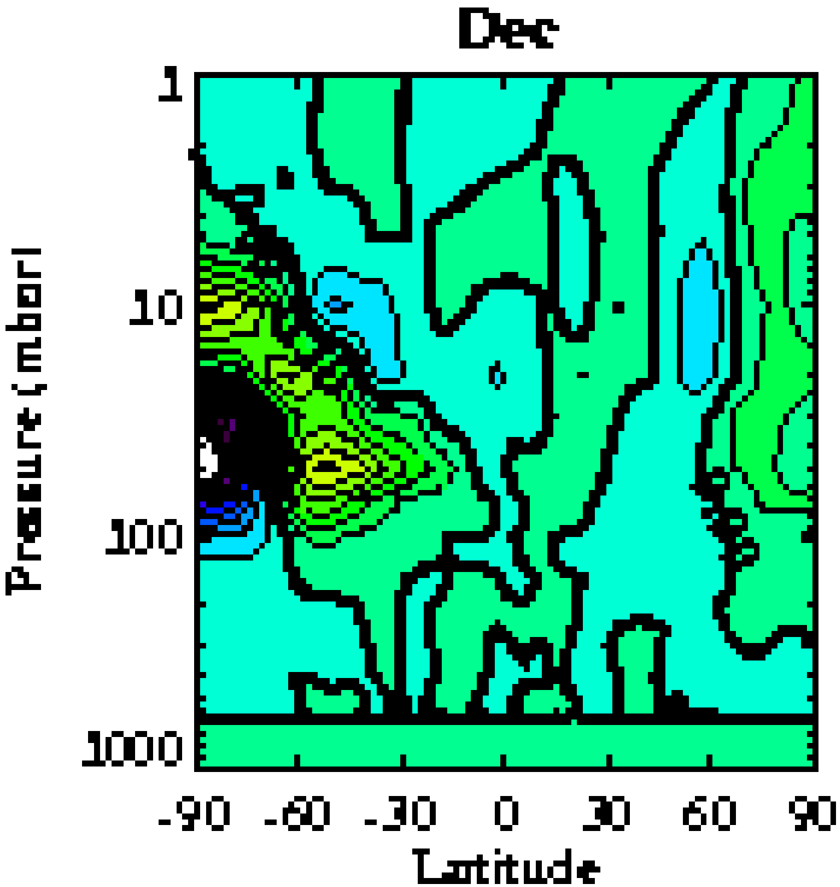
Note negative change in middle stratosphere in tropics with positive change in either hemisphere



I speculate that this is an indication of a change in the residual circulation: this can be tested!

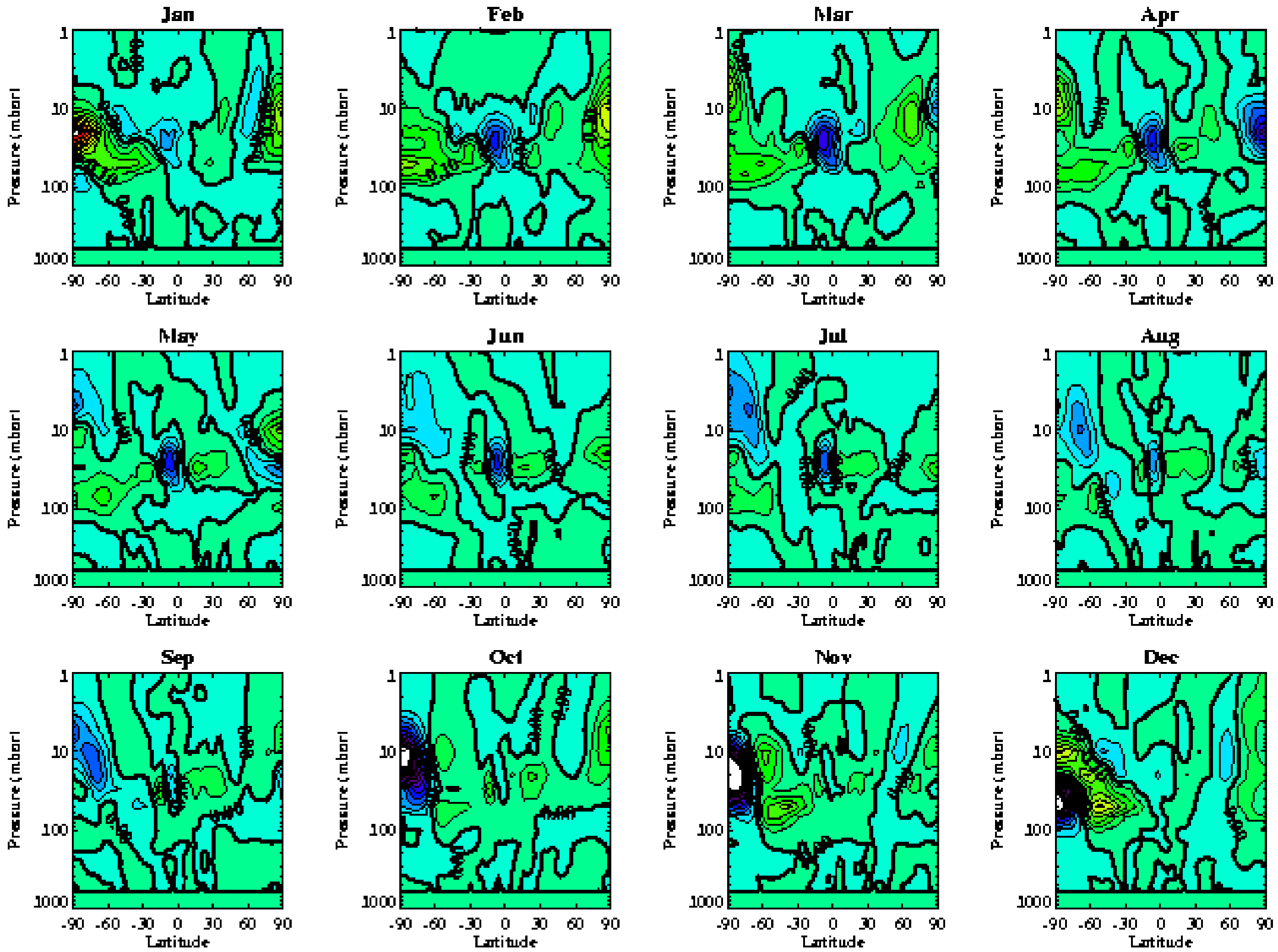
This is the difference between the on-line parameterized ozone Tracer for each 20-year simulation (2000-1980).

Mean Difference Between 20-Year Simulations with Pre and Post Ozone Hole Ozone in Radiation Code: December

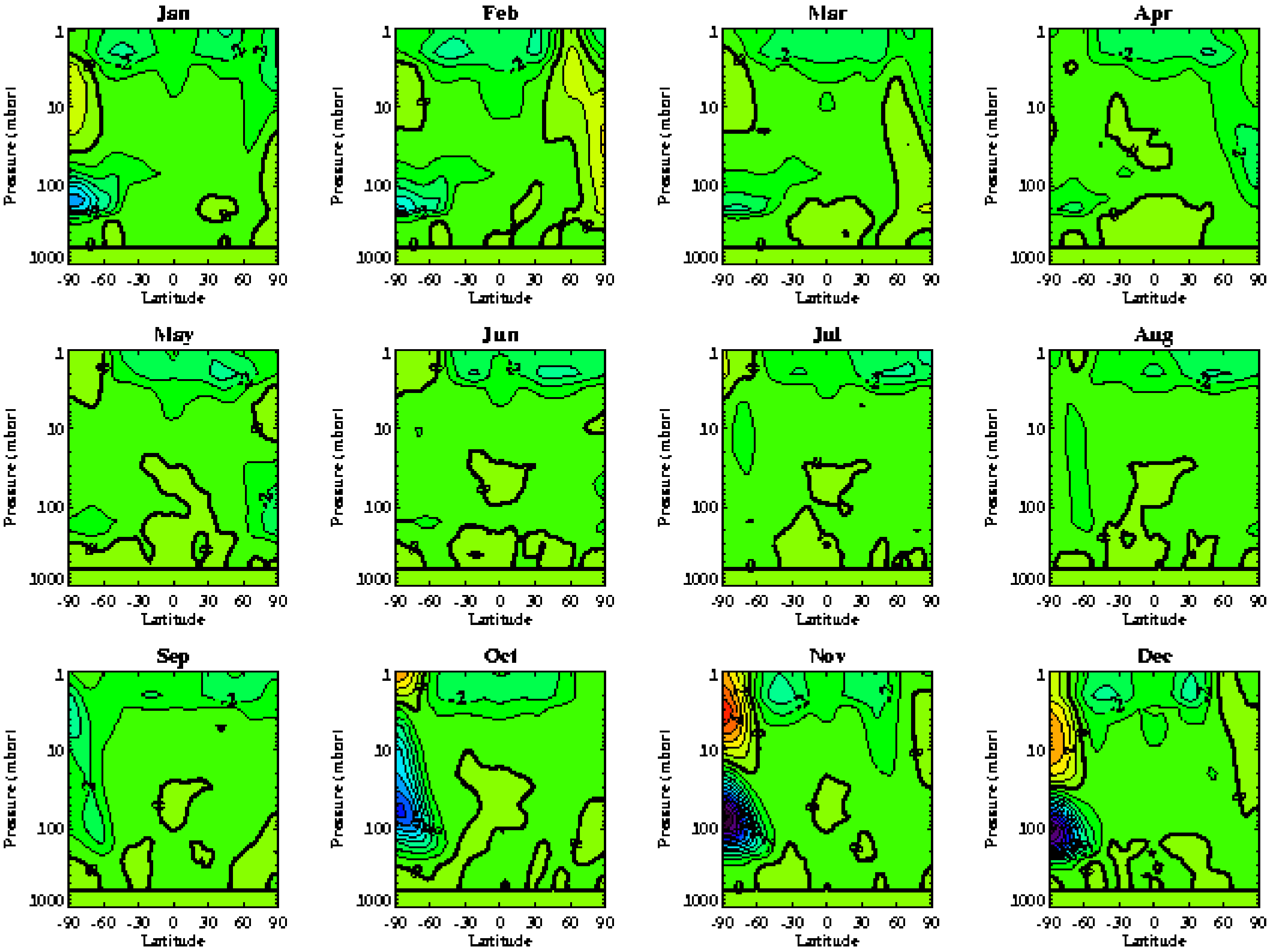


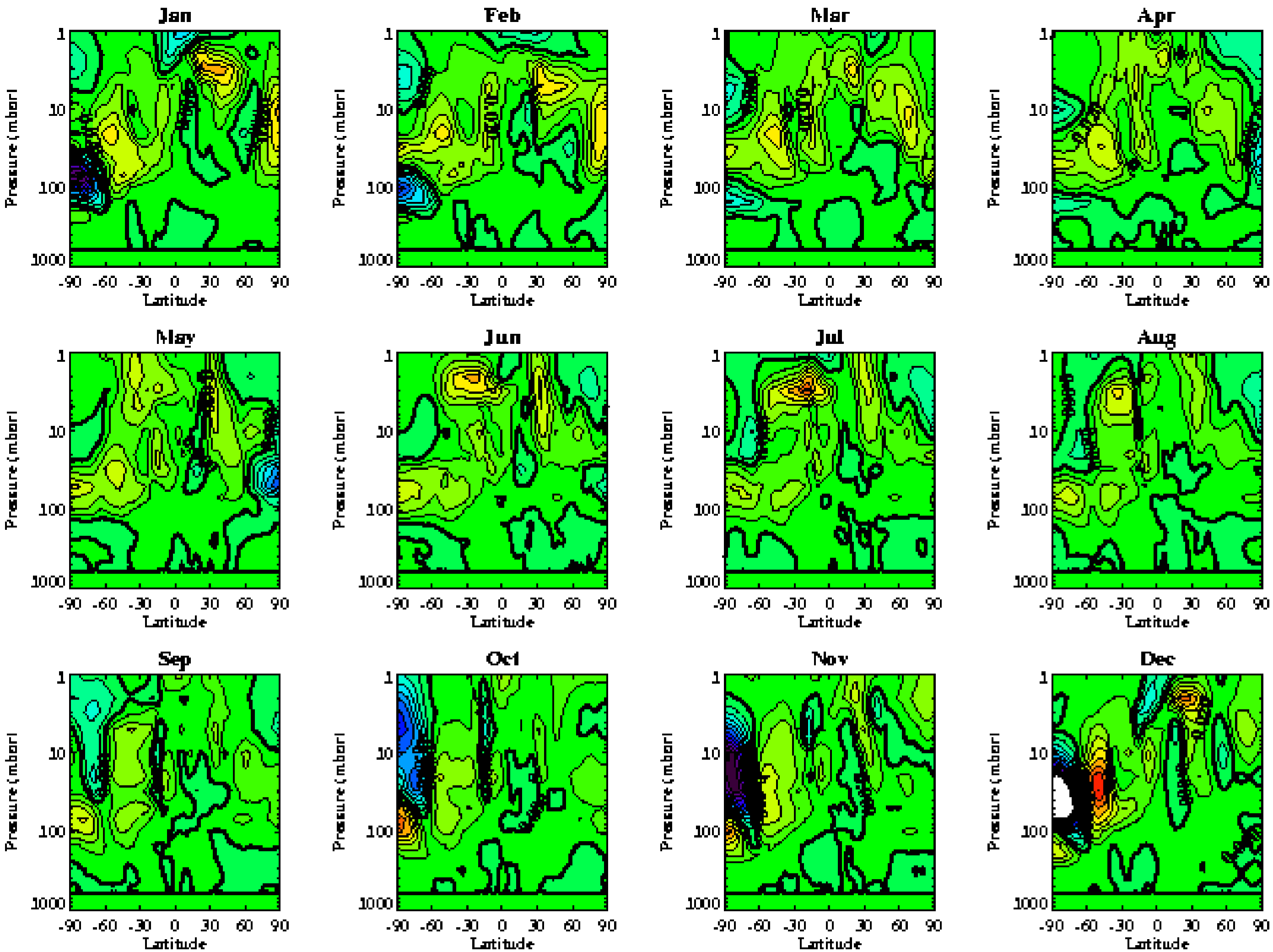
This is the difference between the on-line parameterized ozone Tracer for each 20-year simulation (2000-1980).

Mean On-line Ozone Difference Between 20-Year Delta Ozone Simulations

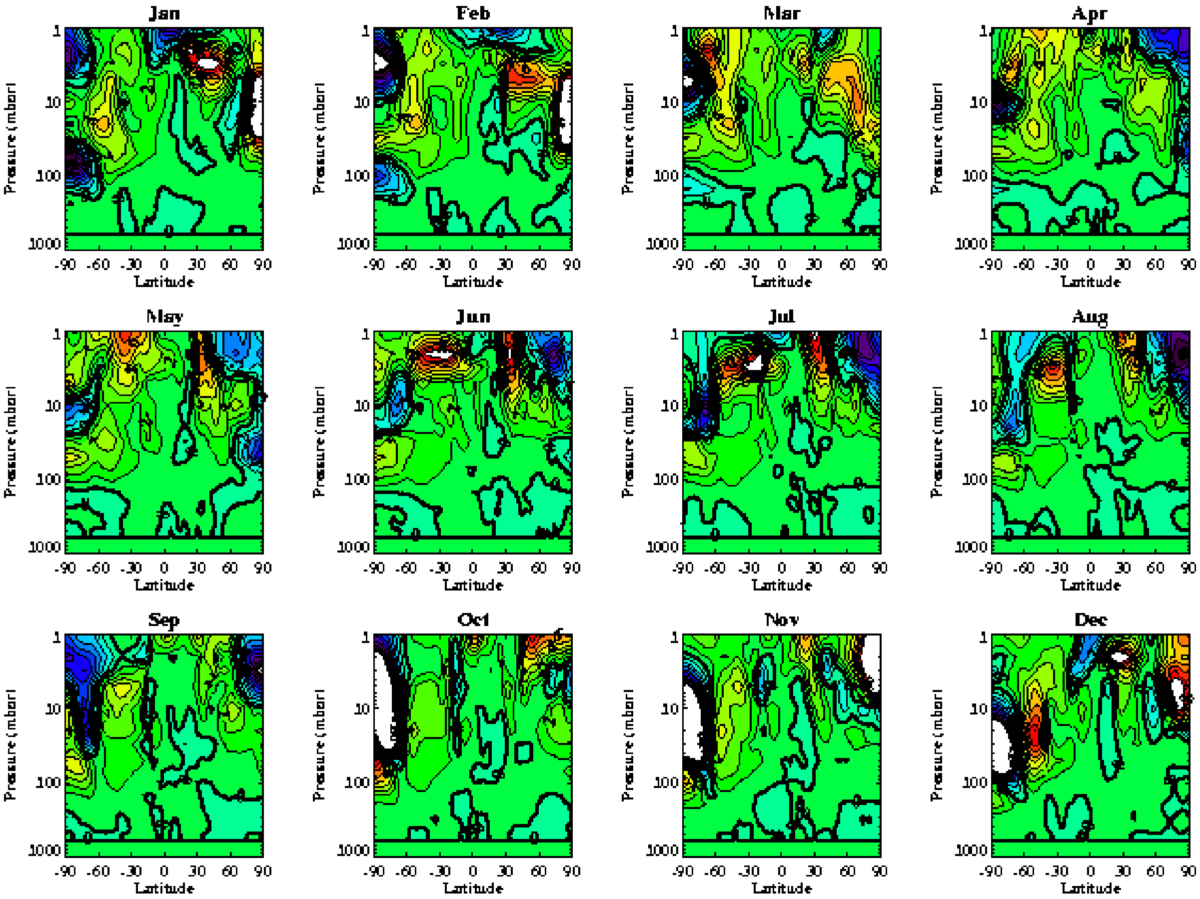


Mean Temperature Difference Between 20-Year Delta-Ozone Simulations

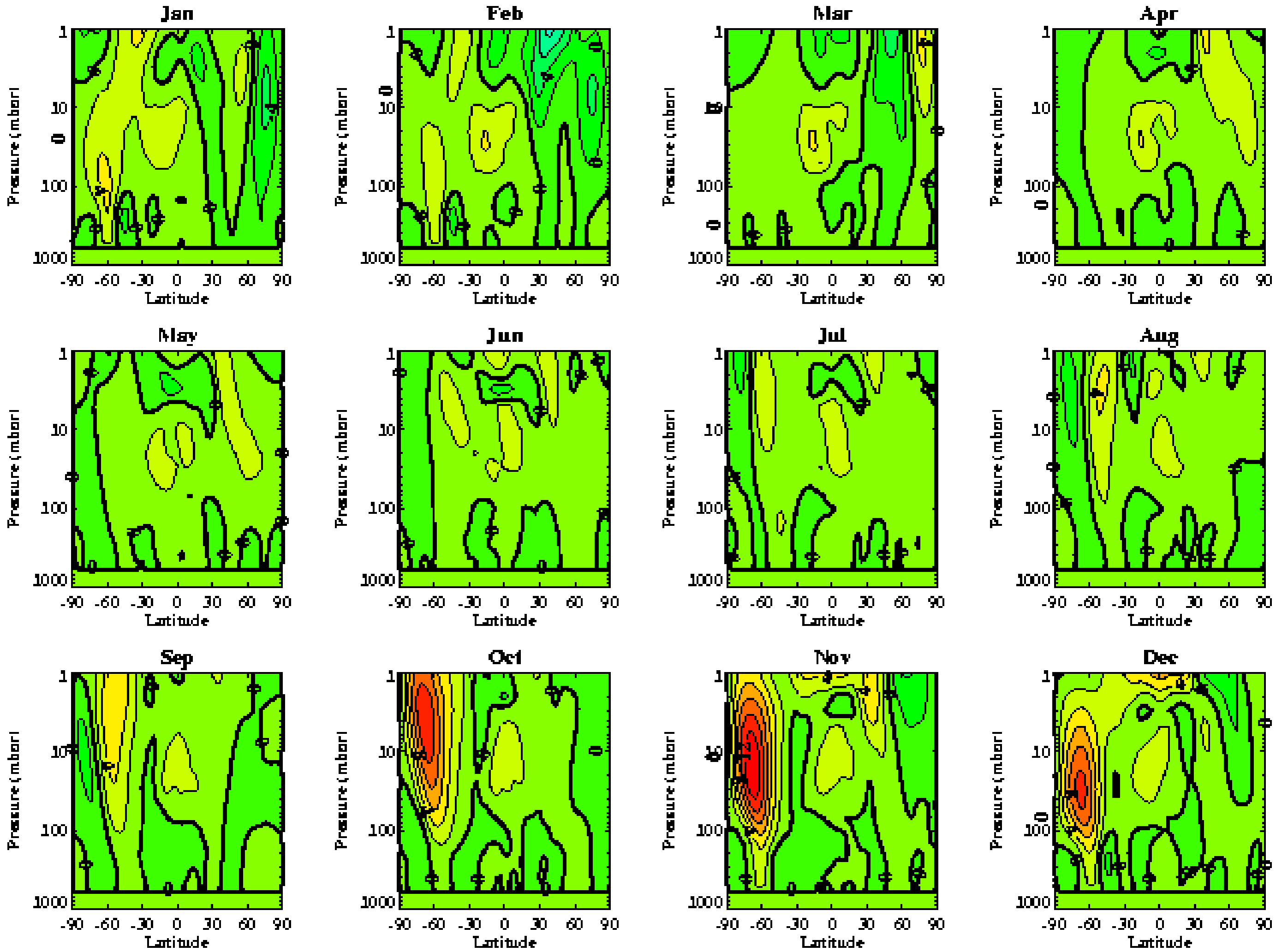


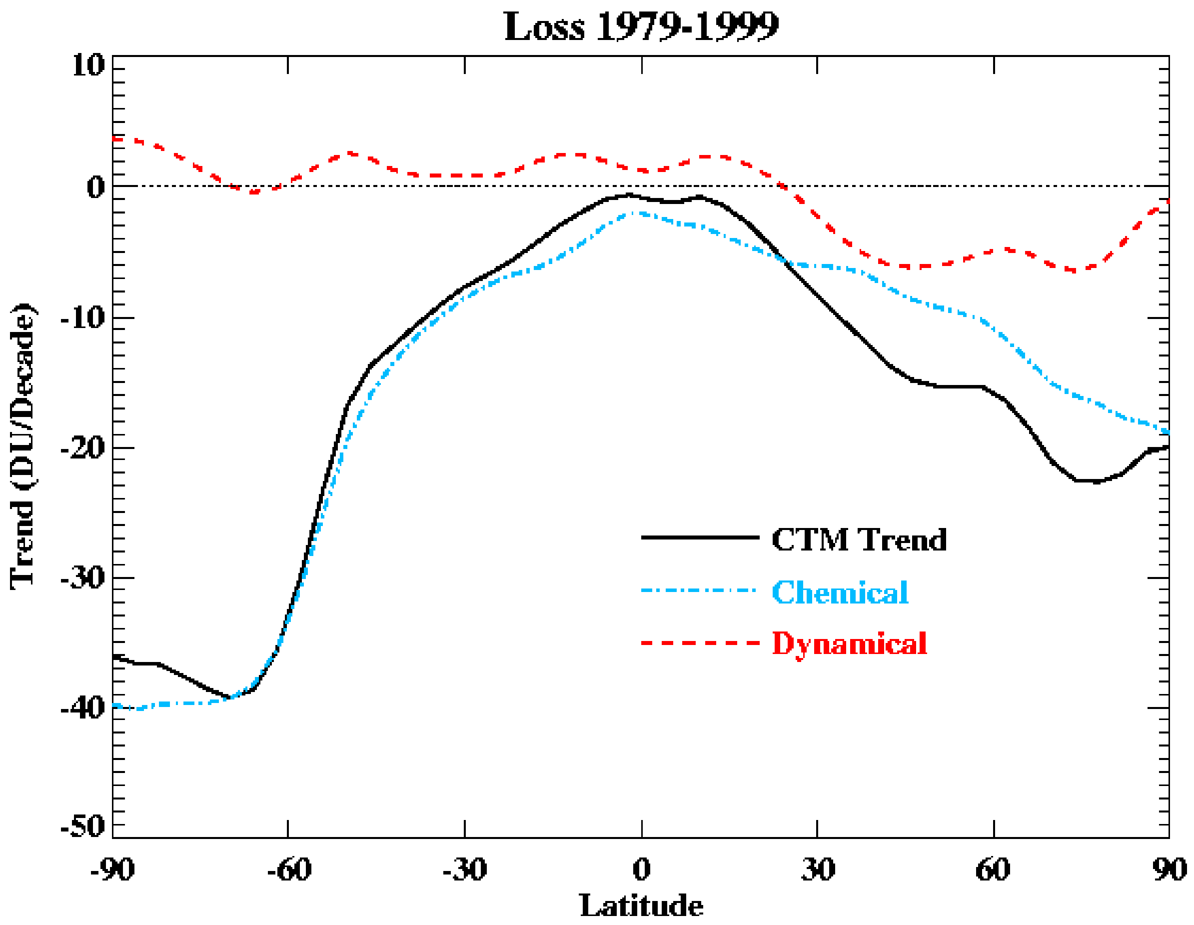


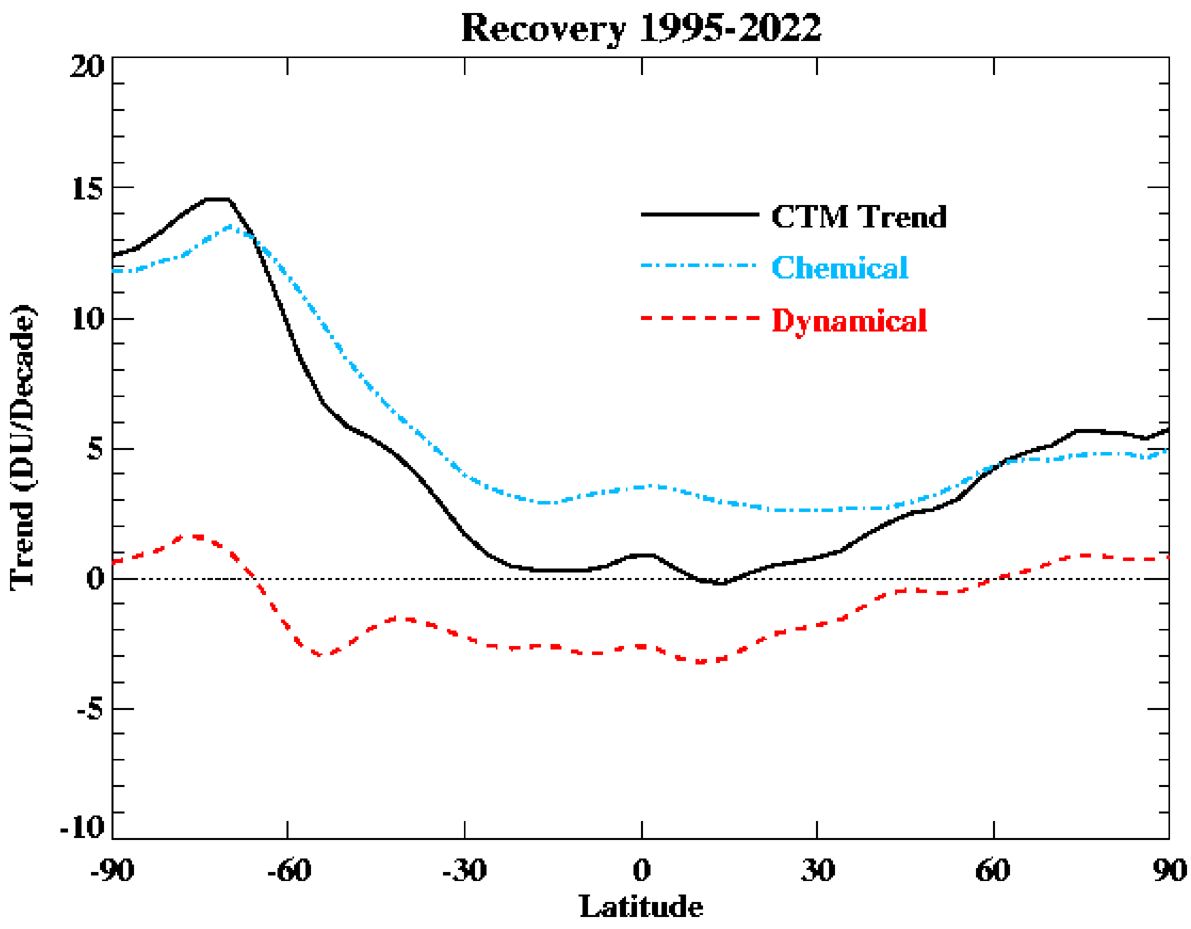
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Pressure (mbar)
Latitude
1
10
100
1000
-90
-60
-30
0
30
60
90


Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Pressure (mbar)
1
10
100
1000
-90 -60 -30 0 30 60 90
Latitude

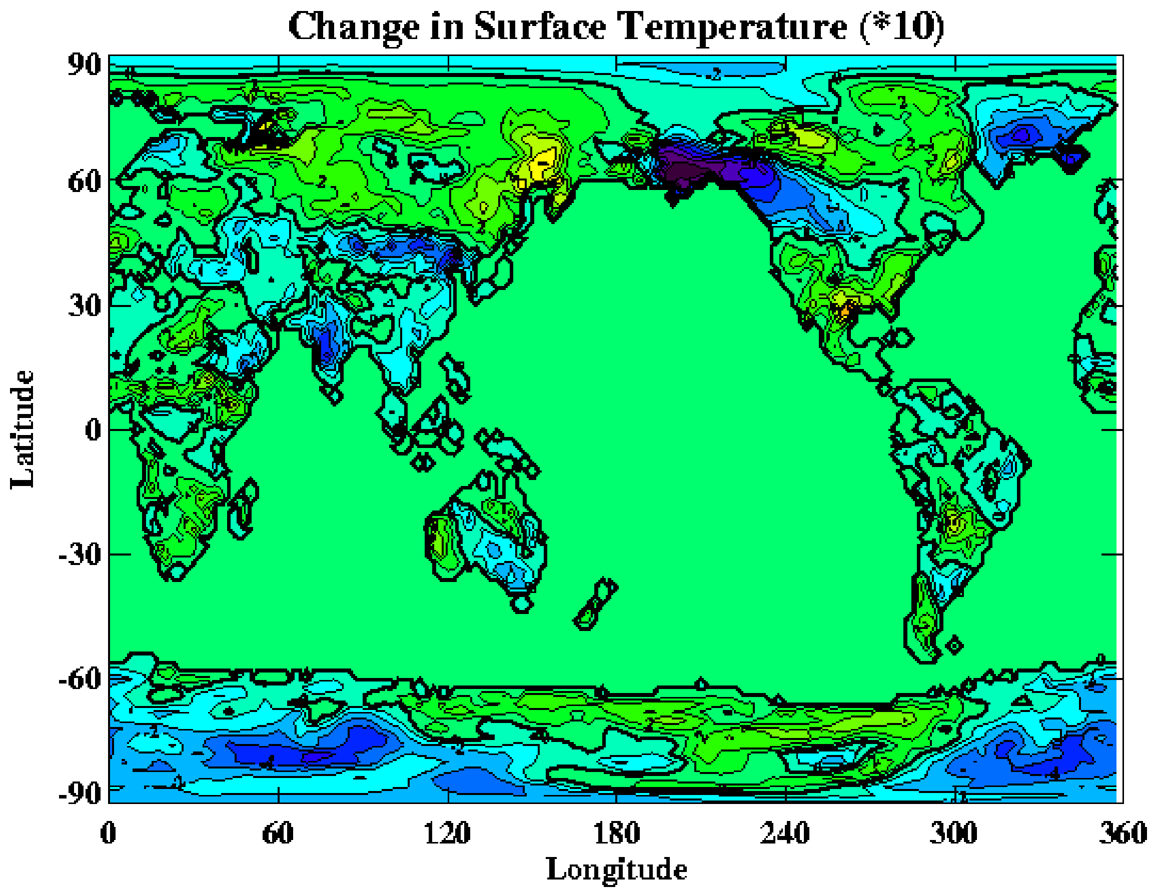
Mean Zonal Wind Difference Between 20-Year Delta-Ozone Simulations



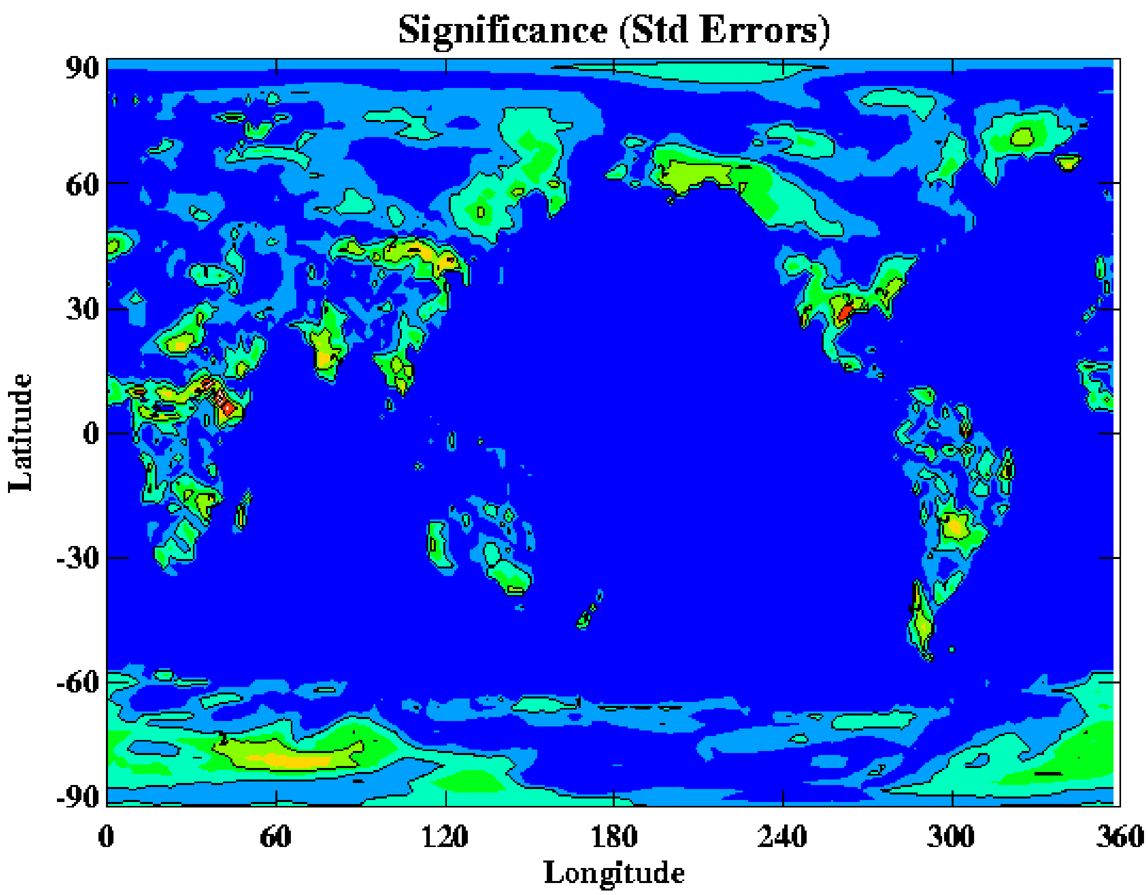

Loss 1979-1999
10
0
-10
-20
-30
-40
-50
Trend (DU/Decade)
-90
-60
-30
0
30
60
90
Latitude
CTM Trend
Chemical
Dynamical

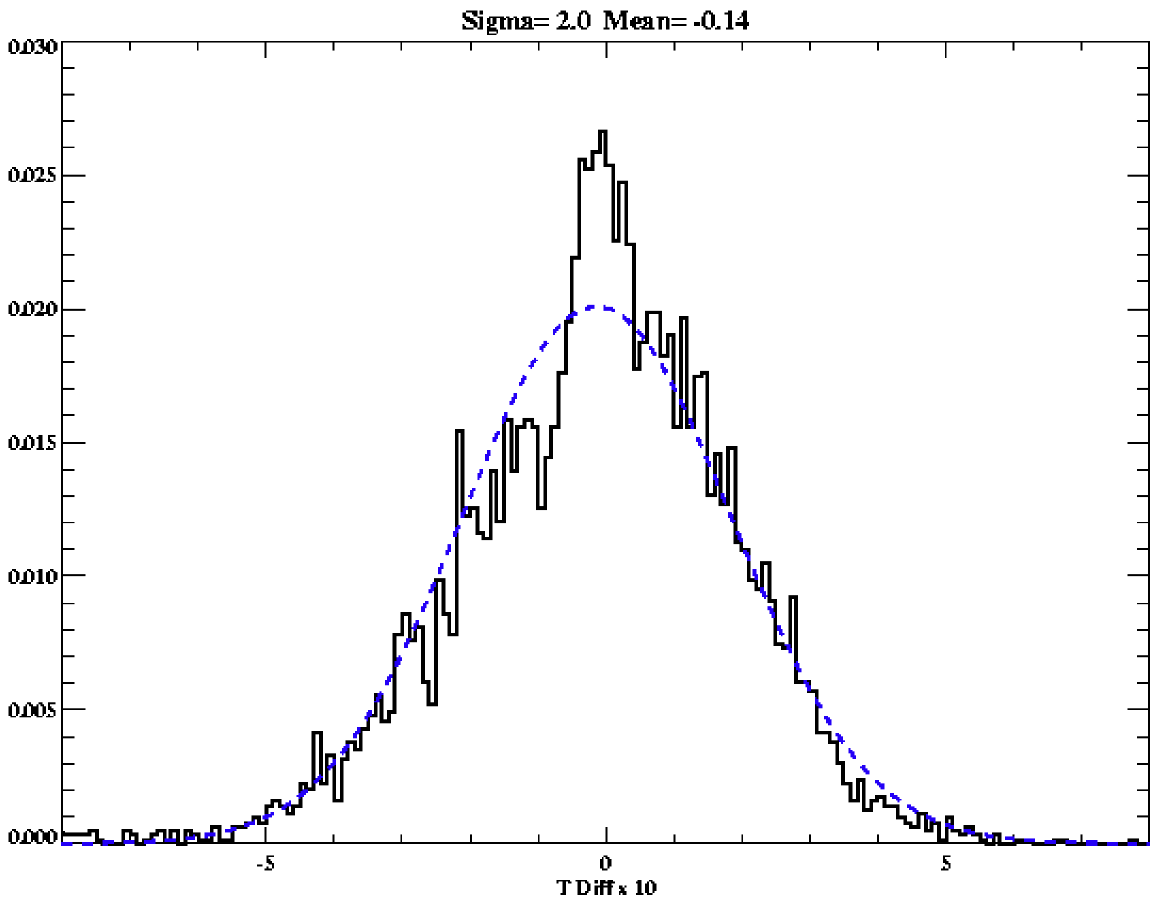

Recovery 1995-2022
CTM Trend
Chemical
Dynamical
Trend (DU/Decade)
Latitude
20
15
10
5
0
-5
-10
-90
-60
-30
0
30
60
90

We can also look at changes in surface climatology



But, SST is held constant at specified values - need reactive ocean


Significance (Std Errors)
90
60
30
0
-30
-60
-90
Latitude
0
60
120
180
240
300
360
Longitude


Sigma= 2.0 Mean= -0.14
0.030
0.025
0.020
0.015
0.010
0.005
0.000
-5
0
5
T Diff x 10

Summary of Simulations

CTM

- **50-year hindcast/ forecast with FVGCM winds**
- **20-year rerun without volcanic aerosol**
- **9-year rerun with Pinatubo in 1975**

GCM

- **50-years with Hadley SST, 1949-1999**
- **50-years with AMIP repeating SST**
- **50-years with mean of Hadley SST repeating**
- **20-years with 1978-1980 ozone climatology**
- **20-years with 1998-2000 ozone climatology**